A Single-Mode, Diode-Pumped Lma Laser To Probe The Spin Orientation Of Ensembles Of 3he And 4he

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A SINGLE-MODE, DIODE-PUMPED LMA LASER TO PROBE THE SPIN ORIENTATION OF ENSEMBLES OF ^{3}He AND ^{4}He

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Abstract - A diode-pumped Nd:Lanthanum Magnesium Hexaluminate laser was constructed which provides up to 15 mW of single-mode, tunable CW emission at 1083 nm. By appropriately polarizing the narrow-band laser emission (< 10 MHz), the laser can be used to determine the populations of the magnetic substates of the He(2^3S_1) atoms. The laser is tuned to one of the absorption peaks of the helium metastable atom by tilting a thin (1 mm) solid, coated etalon placed inside the laser cavity and the absorption is measured. The relative absorption is used to determine the ensemble polarization; the absolute absorption yields the metastable density.

Introduction.

A number of exciting, new applications for optically pumped ensembles of ^{3}He and ^{4}He are being pursued in nuclear scattering (1) and the field of quantum fluids (2). These applications are possible because of the extraordinary efficiency that newly developed, tunable lasers bring to the optical pumping process (3). A high power, Nd-doped lanthanum-magnesium-hexaluminate (LMA) laser tuned to the helium resonance at 1083 nm, for example, makes it possible to obtain near perfect orientation of the electron spins in ^{4}He(2^3S_1) (4) and the nuclear spins of ^{3}He (3) by optical pumping. Polarizations of 90% are now routinely available.

In these new applications the ensemble polarization must be accurately known. Several techniques have been developed to obtain a measurement of the polarization. The earliest method relied on a helium discharge lamp to interrogate the magnetic sublevels of the 2^3S_1 metastable atom (5) by absorption. The accuracy available with this method is severely limited, however, since the spectral width and shift of the resonance lines from the discharge lamp relative to the absorption profile are generally not known. Two other methods for polarization measurements are restricted to ^{3}He -an optical technique in which the circular polarization of a line at 668 nm emitted by the discharge is observed (6) and nuclear magnetic resonance (NMR) (5). Both these methods suffer problems concerning their accuracy; the former was calibrated before the time of lasers; the latter depends on an accurate determination of cell pressure.

The optical absorption method is, in principle, free of some of the limitations of the above methods and is potentially an absolute

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measurement of polarization for both ^3He and ^4He. A single-mode, single-frequency laser, used in place of the discharge lamp, can be tuned to the center of a specific spectral absorption component. If this narrow-band tunable laser is appropriately polarized, the relative densities of the magnetic sublevels can be directly observed and the polarization measured.

Energy levels in Helium.

The probe laser is tuned to the 2^3S_1 - 2^3P transitions in helium near 1083 nm. In figure 1 the pertinent levels are shown along with the absorption processes of interest. The solid lines shown indicate the levels connected when right-hand circularly polarized light is incident on the discharge cell parallel to an external magnetic field.

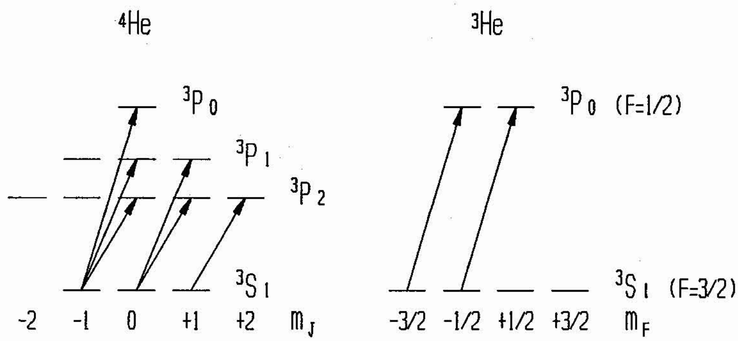

Figure 1.

It is clear from the diagram that the polarized, appropriately tuned probe laser can be used to monitor selectively the populations of the magnetic sublevels.

The Single-mode Probe Laser.

The probe laser is a Nd-doped crystal of $LaMgAl_{11}O_{19}$ which is end-pumped by a 500 mW diode laser at 800 nm (7). Figure 2 is a schematic representation of the laser cavity. A Lyot filter (t=6 mm) and a 1 mm

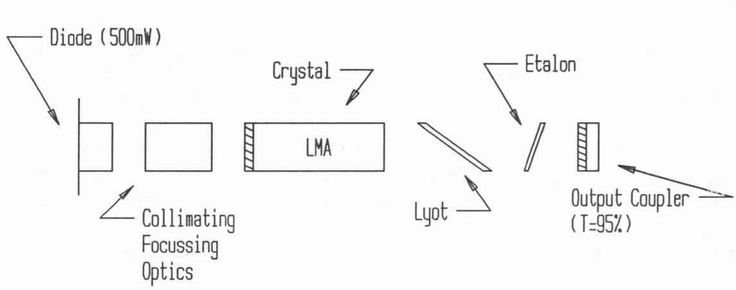

Figure 2.

thick etalon (50% reflective coating at 1083 nm on each surface) provide narrow-banding and tuning capability. With this cavity tunable, single-mode power exceeding 15 mW is obtained. The emission bandwidth is less than 10 MHz, the limiting resolution of our scanning FP interferometer. The laser is quasi-continuously tuned through the helium resonance lines, depicted schematically in figure 1, by tilting the solid etalon. The laser is easily tuned to oscillate at any of the peaks of the transitions shown. The laser frequency can be scanned easily over the entire 30 GHz range of the helium absorption lines.

Polarization Determination.

The metastable atoms are optically pumped leading to an orientation of the metastable spins. In ^{4}He this yields an electron spin polarization; in ^{3}He the hyperfine interaction orients the nuclear spins and exchange collisions transfer this orientation to the ground state atoms.

The electronic polarization of the metastable atoms of ^{4}He is written as $P_E = (n_3-n_1)/n$ where n_1, n_2, n_3 are the populations of the $m_J = -1$, 0, and +1 levels respectively, and n is the total metastable population. The corresponding levels for the F = 3/2 level of the ^{3}He 2^3S_1 level are labelled n_1 to n_4 for $m_F = -3/2$ to $+3/2$. In ^{3}He the metastable levels and the ground state levels are in spin exchange equilibrium (6) such that the nuclear polarization, $P_N = (N_2-N_1)/N$ where N_1 and N_2 are the populations of the spin down and spin up states of the ground state. The exchange equilibrium condition requires further that $n_1/n_2 = n_2/n_3 = n_3/n_4 = (1-P)/(1+P)$.

If the relative absorption strengths are known, it is easily shown that the relative populations of the magnetic substates of the metastable atoms can be determined and hence, the polarization.

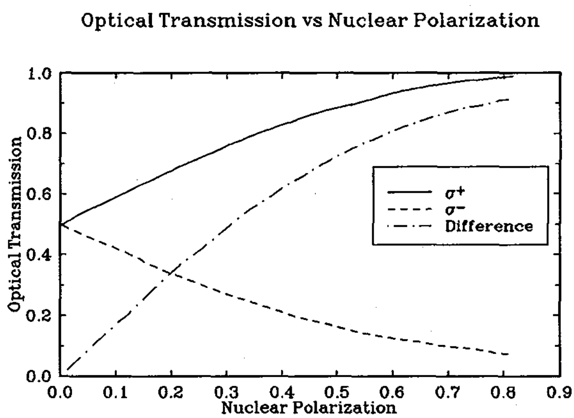

Figure 3.

Experimentally our single-mode laser is passed through a rotating quarter-wave plate and then through the helium discharge cell parallel to an applied magnetic field. The transmission of the probe laser is observed as first $\sigma^+(\Delta m=+1)$ and then $\sigma^-(\Delta m=-1)$ transitions are induced.The absorption is detected synchronously at twice the rotation frequency of the wave-plate. This synchronous signal is simply related to the ensemble polarization. In figure 3 we plot the calculated value of this synchronous signal vs nuclear polarization when the absorption of the probe signal by the metastable atoms at P=0 is 50%. As is seen, the absorption of σ^+ light goes to zero as the nuclear polarization goes to 100% corresponding to a depletion of the population in the n_1 and n_2 levels. In figure 4 we show the buildup of the nuclear polarization with time after the lamp pumped LMA laser emitting three watts of σ^+ polarized light is turned on (circles) and the decay of the nuclear polarization with time after the optical pumping is removed (squares). The data of figure 4 demonstrate the remarkable efficiency

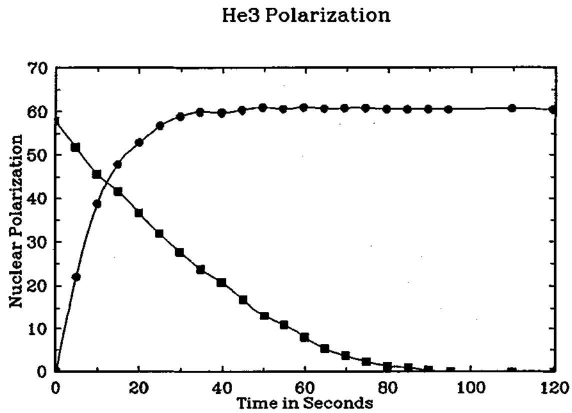

Figure 4.

of the ^{3}He optical pumping process. At early times each absorbed photon orients approximately one nuclear spin.

Measurement of the metastable polarization in ^{4}He is performed in a similar manner. The lock-in signal is directly proportional to the polarization at low absorption. The use of this probe laser to observe metastable polarizations is described in reference 4.

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